Visualization of the state of the atmosphere during the AF447 Event

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Introduction

On the early morning hours on June 01, 2009 Air France Flight 447 disappeared into the Atlantic Ocean at the approximate location of 2°59′N 30°35′W, while en route from Rio de Janeiro, Brazil to Paris, France. The Bureau d'Enquêtes et d'Analyses (BEA) Interim Report [1] states the presence of clusters of cumulonimbus that are characteristic of the Intertropical Convergence Zone (ITCZ) were present, with significant spatial heterogeneity and a life of a few hours. Approximately four hours after take off, the plane's route took it through an intense mesoscale convective system playing a key role into the tragedy that took place.

Aumann et al [2, 3] have suggested that the s-called Tropopause Penetrating Convection (TPC) event might be associated with the fate of AF447. The amount of energy released in a single TPC can be estimated from the associated rain rate and the associated release of latent heat using AIRS and AMSR-E sensor on the EOS Aqua satellite. Hurricanes and Typhoons are seen by AIRS as large clusters of TPC, but most clusters of TPC remain un-named. For the June 1 event, Aumann applied the cluster analysis to demonstrate that 150 km clusters of TPC were observed in the tropical Atlantic at 3:30 AM UT. It is intriguing to explore what additional insight can provided using data from other remote sensing data collected over that area around the same time.

For this short note, we used various data access and visualization tools available at the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC) to demonstrate how easy it is to assess the state of the atmospheric before, during, and after events like the AF447 crash using this multi-sensor approach.

One example of the analysis done was using infrared imagery, which showed the on the planned route, the existence of a cluster of powerful cumulonimbus that is identifiable from 1 h 30 UTC. It is quite noticeable this cluster resulted from the merging of four smaller clusters and its extension from west to east over around 400 km. Other examples use data from MODIS, AIRS, CloudSat and CALIPSO.

Remote sensing data access, visualization and analysis tools at the GES DISC

The GES DISC, is home of the GES Distributed Active Archive Center (DAAC) and offers an abundance of Earth science data, information, and services to research scientists, applications scientists, applications users, and students. The Goddard online visualization application (http://disc.gsfc.nasa.gov/giovanni/) provides a simple and easy way to visualize, analyze, and access vast amounts of Earth science and remote sensing data. The application is comprised of a number of portals, with each tailored to meet the needs of different Earth science research communities. The GES DISC also provides a Hurricane Data Analysis Tool, focused on analyzing hurricanes (http://disc.sci.gsfc.nasa.gov/hurricane/trmm_quikscat_analysis.shtml) that allows analyzing and visualizing satellite and model datasets related to hurricanes ranging from 30 minutes to daily. The available products are: QuikSCAT, TRMM TMI SST, TRMM daily rainfall, NCEP reanalysis, and the merged IR product. The merged IR, which is a TRMM ancillary product archived at DISC, is a product that merges available geostationary satellites 36000 km above the equator. Using Giovanni and the Hurricane Data Analysis Tool, a user can easily and quickly take a closer look at the oceanic, atmospheric and cloud parameters.

Infrared Imagery – Brightness Temperature and Cloud Top Temperature

In the evening before the crash, a cluster of clouds formed in a line West to East across the flight path. Using infrared imagery it is possible to see the strength in the development at the time AF447 was crossing the region. The cumulonimbus clusters are comprised of dense clouds with great vertical development. The tops of the clouds can reach heights higher than 18 km and contain severe up and down drafts, circulating warm and cold temperatures.

The global merged IR product, also known as, the NCEP/CPC 4km Global (60N - 60S) IR Dataset, is globally-merged (60N-60S) pixel-resolution IR brightness temperature data (equivalent blackbody temps), merged from all available geostationary satellites (GOES-8/10, METEOSAT-7/5 & GMS). The availability of data from METEOSAT-5, which is located at 63E at the present time, yields a unique opportunity for total global (60N-60S) coverage.

Using the Hurricane Data Analysis Tool, the global merged IR product was selected to view the brightness temperature (grey scale and false color options are available). The animation of the Merged IR measurements of the first seven hours (at 30-min intervals) on June 1, 2009 (http://disc.sci.gsfc.nasa.gov/hurricane/AFR447/MergedIR_anim.gif) shows how quickly the storm has been developing.

In Figure 1, most of the convection activities are characterized by clouds with cold cloud top temperatures. The very low temperatures define the region in the cumulonimbus clouds that had very high tops reaching the altitude of the tropopause with temperatures reaching -80 °C. What is not seen in the infrared imagery is the vertical temperatures within the cloud structure at the height of the flight path.

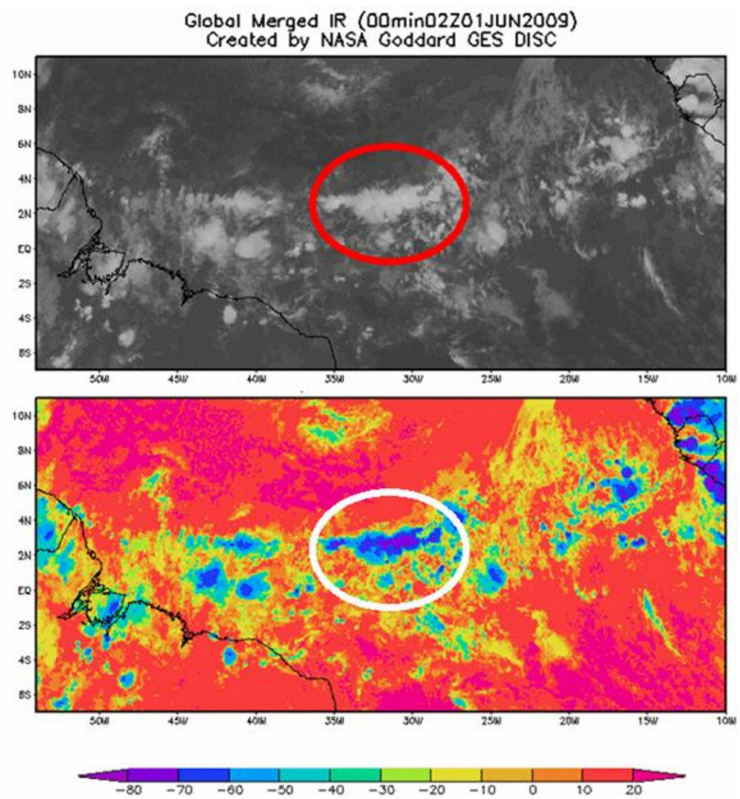

Figure 1. Brightness temperature (top) and false color (bottom) images showing convective activities within ITCZ. The largest mesoscale convection system (MCS) is near the accident site, indicated by a colored circle.

A more localized look of the Merged IR data with the flight path provides more detail in Figure 2 below. The data is once again from the time 02Z and as it can be seen from the flight location marks the plane is about to enter right through the center of the cluster. At approximately 02:10 UTC is when the problems began with the flight systems [1]. The image on the right shows the low temperatures at the cloud top which can contribute to the development of precipitation ice further investigated below.

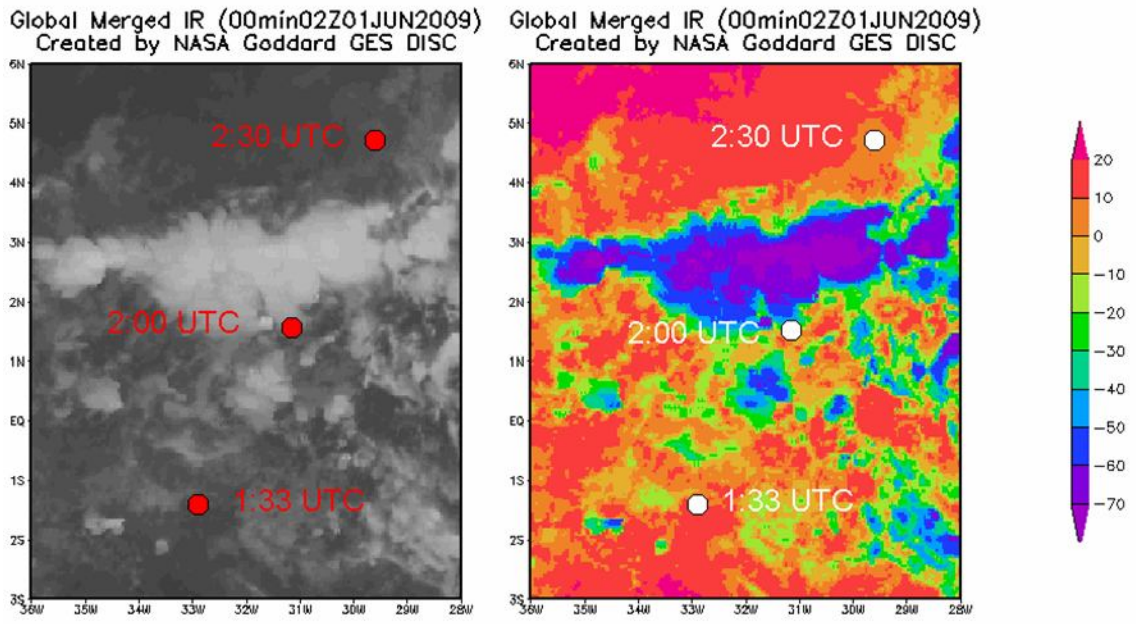

Figure 2. Merged IR images in b/w (left) and false color (right) with AF 447 flight locations marked.

The infrared data is not the only data that shows the cloud top temperature. The MODIS Giovanni provides a quick dynamic visualization of atmospheric parameter using MODIS Terra and Aqua Daily Level 3 data 1x1 degree data. The instance, which can be accessed at http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=MODIS_DAILY_L3, was used to quickly generate the "night only" MODIS-Aqua map of Cloud Top Temperature in Figure 3, which can then be used to verify the findings in the merged IR data.

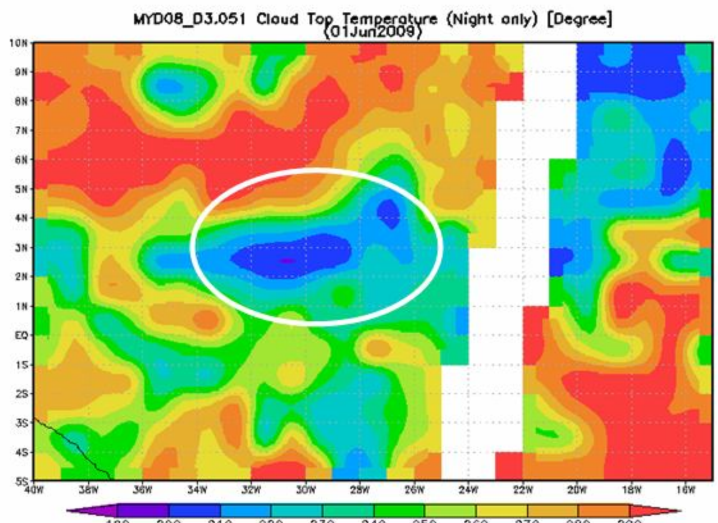

Figure 3. MODIS-Aqua Cloud Top Temperature generated using the MOVAS Giovanni instance.

Another product that can be used to verify the cloud top temperature is the AIRS/Aqua standard daily level 3 gridded product. This product can be generated using the AIRS daily Giovanni instance http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=AIRS_Level3Daily.

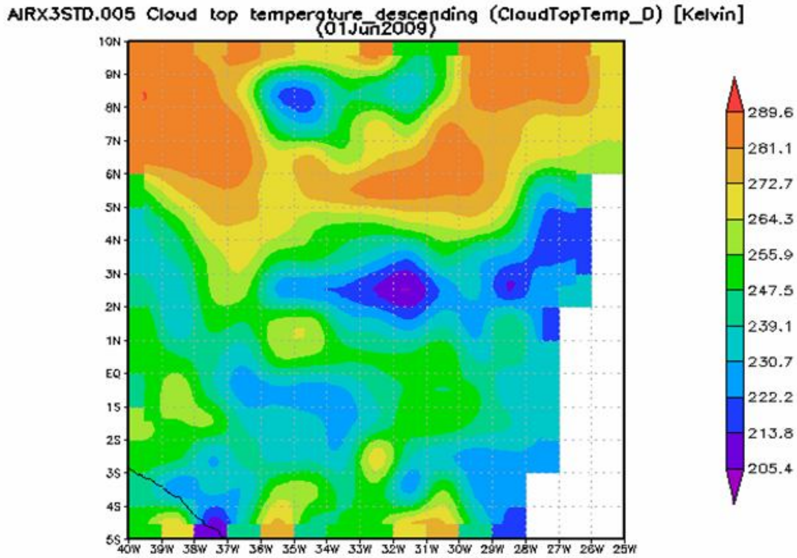

Figure 4. AIRS/Aqua standard daily level3 product Generated using the AIRS Daily Giovanni instance.

Figure 4 was generated using the AIRS instance and shows the cloud top temperature of the descending orbit of the AIRS standard daily product. At a quick glance, the AIRS and MODIS images show a similar structure as the merged IR image and the values measured of the parameter show very low temperatures in the center of the cluster.

Surface Winds and Sea Surface Temperatures

The cluster was large in size and showed very strong movement contributed by convergence of airflows in different directions and the warmer sea surface temperatures at the accident site. The strong winds at the surface at convergence cause an updraft of the warm temperatures from the sea surface feeding the intensity of the cluster. As the storm matures the surface rains increase with adjacent updrafts and downdrafts. Figure 5 shows daily QuikSCAT sea surface wind vectors and TRMM daily rainfall images produced using the Hurricane Data Analysis Tool. The ITCZ is located where the NE wind meets the SE wind.

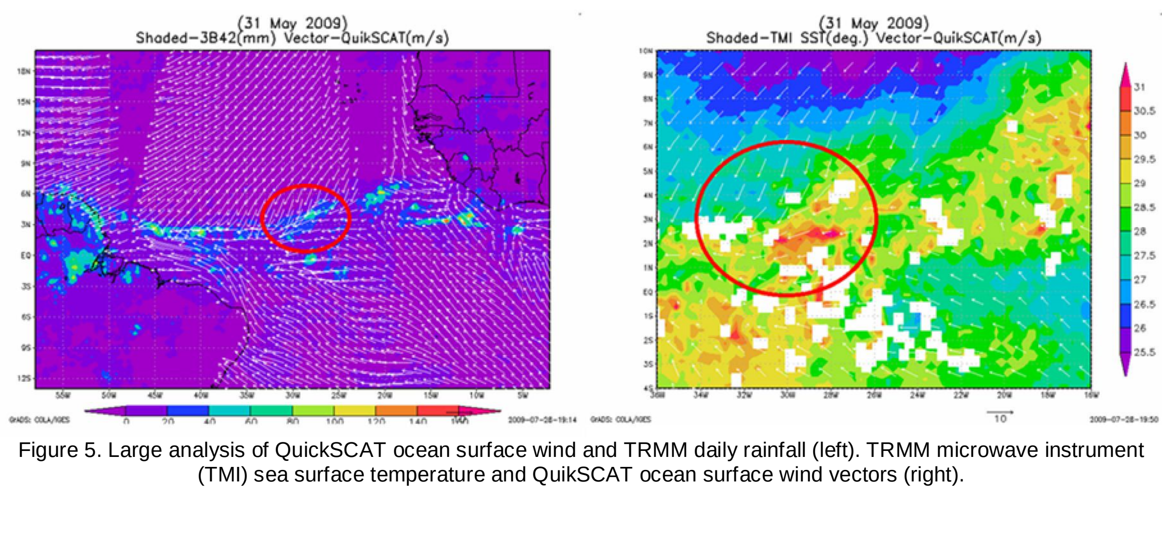

Figure 5. Large analysis of QuickSCAT ocean surface wind and TRMM daily rainfall (left). TRMM microwave instrument (TMI) sea surface temperature and QuikSCAT ocean surface wind vectors (right).

Rainfall

TRMM passed the accident site around 2:30 UTC. Figure 6 shows the instantaneous surface rainfall (left) and the surface convective rainfall (right). By comparing both rains in Fig. 6, it is evident that the convective rain dominated, indicating the convective nature of the thunderstorms in the accident area. As the raindrops begin to fall, the frictional drag between the raindrops and the surrounding air causes the air to begin a downward motion. The descending saturated air soon reaches the level where it is colder than its environment. At this level, its rate of downward motion is accelerated which is the downdraft.

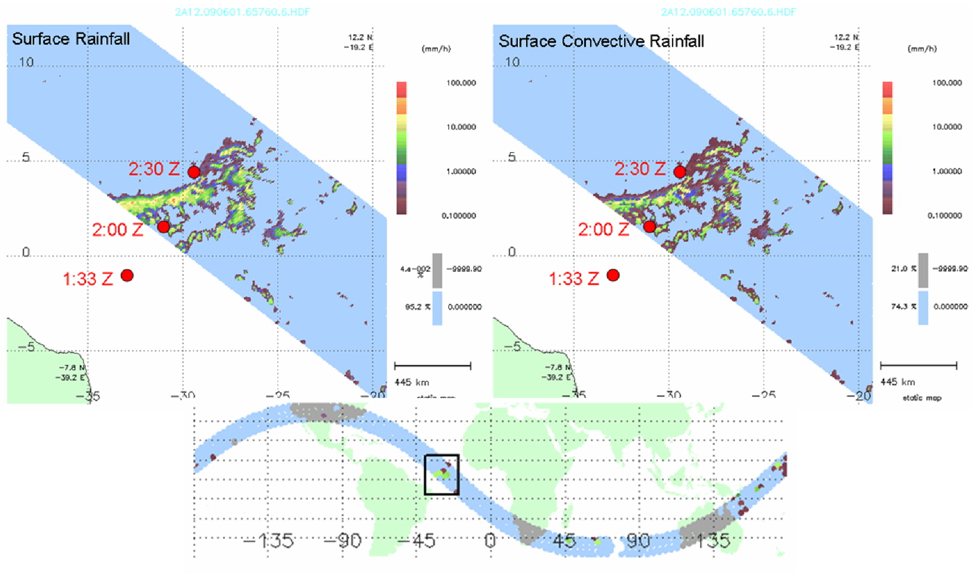

Figure 6. TMI surface rainfall maps (2A12) around 2:30 UTC, generated by TRMM Orbit Viewer. Left: surface rainfall; Right: surface convective rainfall.

Ice Development

The most favorable conditions to produce ice are generally located in the central region of the vertical structure of the cumulonimbus. In these dense clouds the precipitation is a combination of ice crystals and water droplets that both exist in the structure at temperatures below freezing.

The 2-D maps In figure 7,further indicate that in some areas, convective activities can reach the top layer (14 – 18 km) of the maximum instrument measurement. The TRMM data 2A12 is accessible from the GES DISC through the Mirador search and order interface described below.

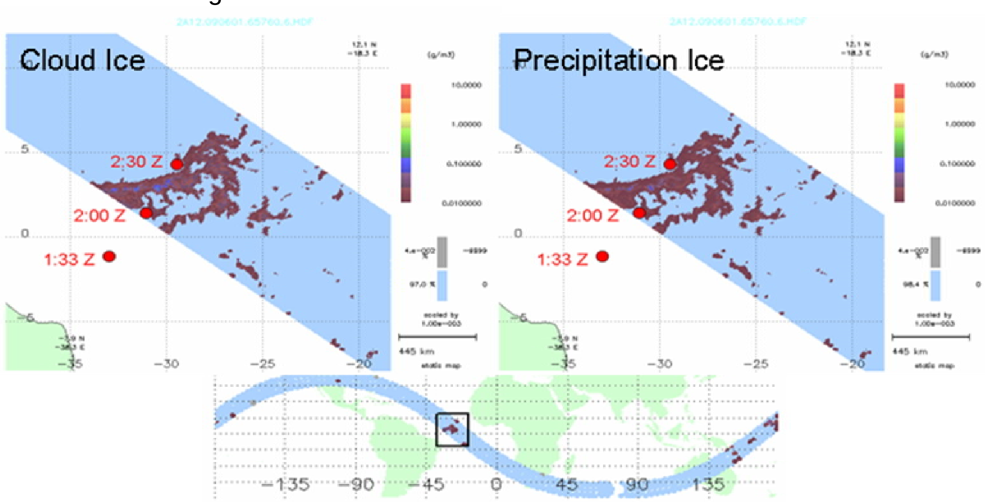

Figure 7. TMI hydrometeor profile maps (2A12) on Layer 14 (14-18 km) around 2:30 UTC, generated by TRMM Orbit Viewer. Left: cloud ice, Right: precipitation ice.

In Figure 8, a 3D precipitation ice also confirms this. These images of the TMI 2A12 product in figure 7 and 8 were generated using the TRMM Orbit Viewer and is in development to be included in a Giovanni instance.

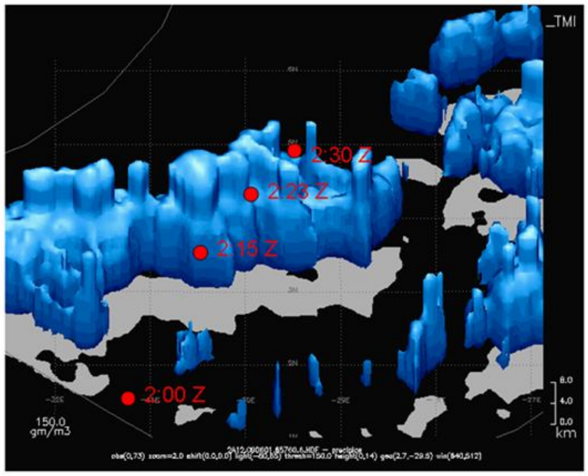

Figure 8. TRMM 3-D TMI precipitation ice (2A12), generated by TRMM Orbit Viewer.

The TRMM Orbit Viewer can be downloaded from the GES Precipitation DISC from the following URL: http://disc.sci.gsfc.nasa.gov/precipitation/additional/tools/trmm_ov.shtml. Note that TRMM had experienced a Precipitation Radar anomaly since May 29, 2009, resulting in missing data, the latest available data will not be available until early fall.

Vertical Analysis

It is important to look at the environmental parameters of the vertical column of the clusters lower in the troposphere where the flight path would have followed. The Giovanni A-Train (http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=atrain) demonstrates its ability to quickly plot data from A-Train instruments by using the following run: http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/results.cgi?wsid=124888048820547&app=jnrcalipso-h2p&instance_id=atrain&sid=12488801938030&gsid=atrain_128.183.164.119_1248879471&selectedMap=&overridePreferences=1

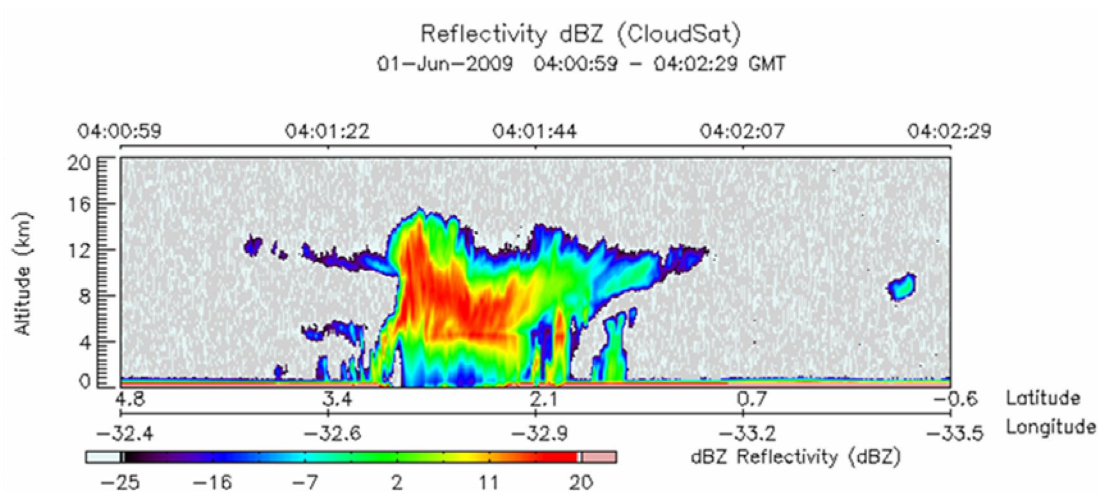

Figure 9. CloudSat measurements of Reflectivity in a couple of hours after the disappearance of AF447 about 200 km from the AF447 flight path. The data from the descending node of A-Train on June 1, 2009 show the state of the atmospheric column at that time and carry evidences of strong convection throughout the entire tropospheric column, up into the tropopause, even at that distance from the flight path. The plot was produced using the Giovanni A-Train Data Depot.

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Near-Real Time support: The GES DISC also has developed a near-real time (NRT) processing system that allow producing and examining of multi-layered NRT satellite data. The data produced can be viewed in GoogleEarth, just hours after satellite overflight.
Two examples of NRT data are:

(1) CALIPSO expedited browse, that GES DISC acquires from Langley Research Center (LaRC)and reformats into KML (Keyhole Markup Language**)** used by GoogleEarth,
(2) Various AIRS parameters served through a Web Map Server (WMS) and also made accessible via GoogleEarth.

Figure 10 shows a snapshot from GoogleEarth, where two layers of NRT data (CALIPSO lidar vertical profile of attenuated backscatter, and AIRS horizontal swath of Brightness Temperatures (Tb) at 11um) are simultaneously viewed. Both data were acquired in the area of the tragic end of Air France flight 447 within a couple of hours after the event and were available shortly after.

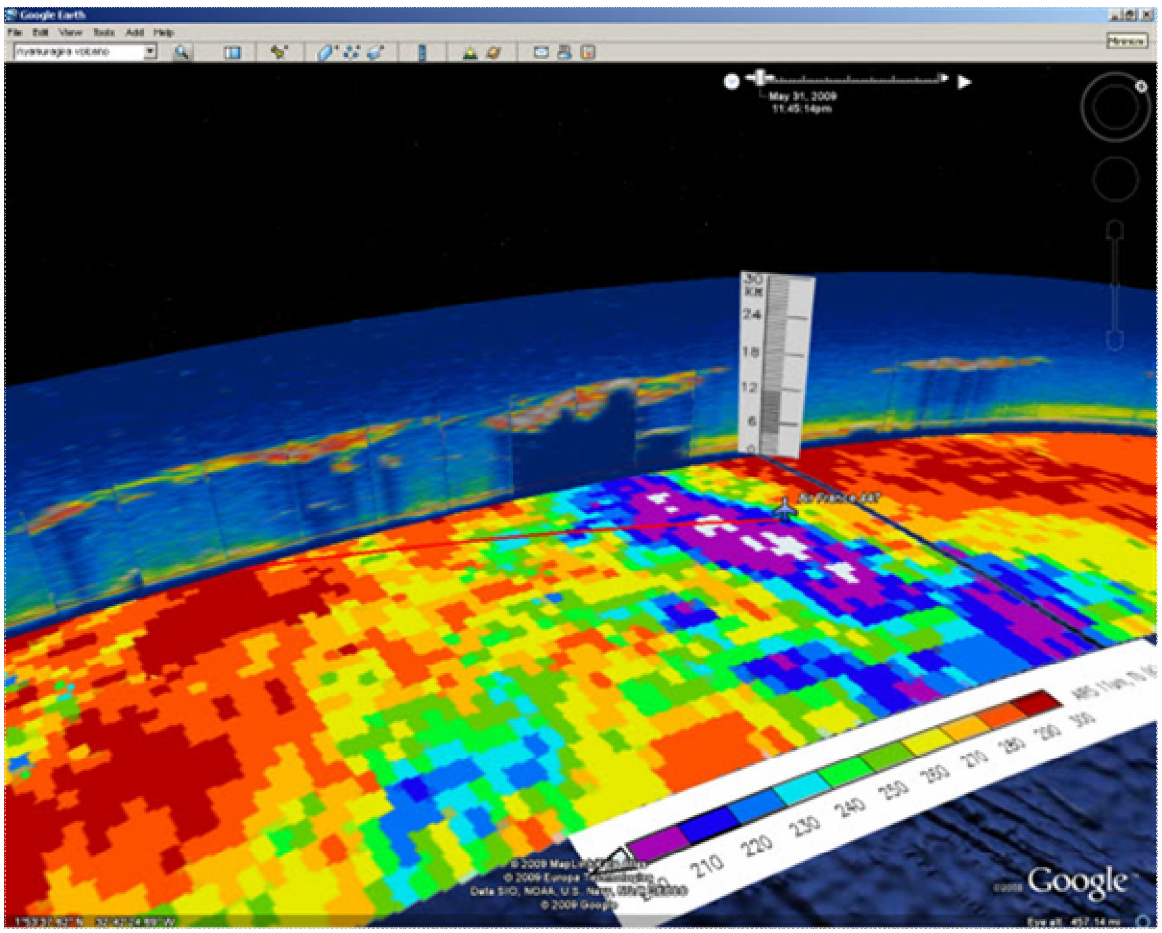


Figure 10. GoogleEarth snapshot with two layers of NRT data: CALIPSO lidar vertical profile of attenuated backscatter, and AIRS horizontal swath of Brightness Temperatures (Tb) at 11um. The red line represents the approximate flight path of AF447.

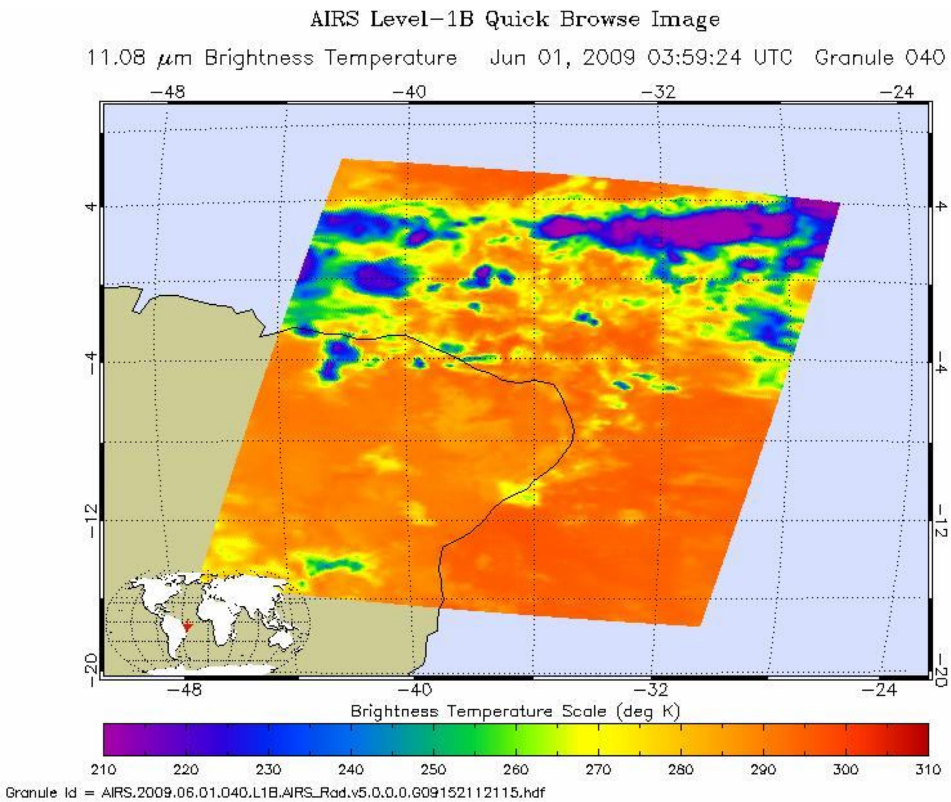
CALIPSO reveals extremely high clouds, reaching altitudes beyond 15 km, and AIRS Tb, colder than 200 K (the bright gray pixels), are an additional evidence to the extreme altitudes of the cloud tops as well as to the horizontal extent of this massive convective storm. The thick red line represents the approximate flight path of AF447, and the icon shows the approximate location of the last transmission from the airplane. The example of the original KMZ file containing these data can be downloaded from here (http://disc.gsfc.nasa.gov/hurricane/AF447/AirFrance447.kmz). In fact, the entire A-Train formation flew over the area at that time in a descending (night) node, and AIRS/Aqua swath and CALIPSO curtain represent approximately the coverage of all A-Train instruments. Hence, more data, relevant to this tragic event, like upper tropospheric temperature and humidity from MLS, can be examined from the A-Train Data Depot.

Other related Data Services at the GES DISC

Satellite and model data measuring various Earth science parameters can be easily accessible through the tools and services provided by the GES DISC. Not only is Giovanni an efficient way to visualize and access data, but the Mirador Search and Download tool (http://mirador.gsfc.nasa.gov/) is available. Mirador has a drastically simplified, clean interface and employs the Google mini appliance for metadata keyword searches. Other features include quick response, data file hit estimator, Gazetteer (geographic search by feature name capability), and an interactive shopping cart. Users have the capability to download multiple datasets and provide users with the ability to subset data spatially, temporally and by parameters by using the interface or scripting a build of URL's of the form:

http://mirador.gsfc.nasa.gov/cgi-bin/mirador/granlist.pl?maxgranules=100&dataSet=AIRIBRAD&version=005&location=(2.,-31.),(4,-29.)&searchType=Location&event=&startTime=2009-06-01%200:30:00&endTime=2009-06-01%204:30:00%22

The above search url will return an AIRS L1B IR radiances data file over the location of the crash, and will give a browse (quick preview) image (see below). To perform a more robust search the input parameters such as the dataset, startTime, endTime and location can be changed. Also, data from several sensors can be search at once, e.g., "AIRS OR MODIS OR TRMM".



To Access Data Used In This Report

Merged IR: The global merged IR product, also known as, the NCEP/CPC 4km Global (60N - 60S) IR Dataset, globally-merged (60N-60S) pixel-resolution IR brightness temperature data (equivalent blackbody temps), merged from all available geostationary satellites (GOES-8/10, METEOSAT-7/5 & GMS).

Data Holdings and Access: ftp://disc2.nascom.nasa.gov/data/s4pa/TRMM_ANCILLARY/MERG/

Hurricane Analysis Tool: http://disc.sci.gsfc.nasa.gov/hurricane/trmm_quikscat_analysis.shtml

TRMM TMI SST: Sea surface temperature derived from TRMM microwave instrument.
(also available in the Hurricane Data Analysis Tool, see link above)

Data Access: http://ssmi.com/tmi/

QuikSCAT: Ocean surface wind derived from SeaWinds on QuikSCAT

Data Holdings and Archive: http://podaac.jpl.nasa.gov/DATA_CATALOG/quikscatinfo.html

Hurricane Analysis Tool: http://disc.sci.gsfc.nasa.gov/hurricane/trmm_quikscat_analysis.shtml

TRMM TMI: TRMM Microwave Imager (TMI) Level 2 Hydrometeor Profile Product. The TMI profiling algorithm (2A12) generates vertical profiles of hydrometeors from TMI brightness temperatures by blending the radiometric data with dynamical cloud models.

Data Holdings and Access: http://mirador.gsfc.nasa.gov/cgi-bin/mirador/presentNavigation.pl?tree=project&project=TRMM&dataGroup=Orbital&dataset=2A12:%20Hydrometeor%20Profile%20(TMI)&version=006

A-Train: A collection of 5 satellites flying in formation taking near simultaneous measurements of Earth science parameters. A-Train sensor (MODIS, AIRS, OMI, CloudSat, CALIPSO, PARASOL) data can be seen and/or accessed from:

Giovanni A-Train http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=atrain

Data Holdings and Access: http://disc.sci.gsfc.nasa.gov/atdd/data-holdings

MODIS:
MOVAS: MODIS Daily Giovanni instance http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=MODIS_DAILY_L3

Data Holdings and Archive http://disc.sci.gsfc.nasa.gov/AIRS/data-holdings

AIRS
AIRS Daily Giovanni instance: http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=AIRS_Level3Daily

Data Holdings and Archive http://disc.sci.gsfc.nasa.gov/AIRS/data-holdings

References
1. BEA Interim Report, http://www.bea-fr.org/anglaise/actualite/af447/interim.report.info.html, Retrieved on July, 29, 2009
2. H. Aumann, Correlation of severe storms identified with AIRS and heavy precipitation measured with AMSR-E on the EOS Aqua, IGARSS'09, July 2009
3. H. Aumann, Ruzmaikin and DeSouza-Machado, "Clusters of Troposphere Penetrating Convective Systems and the Correlation with Hurricanes and Typhoons", submitted to J. Climate May 2009